

Appendix A

Experimental Protocol and Composition of Exposure Atmospheres

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES^a

Facility/Sponsor	U.S. Environmental Protection Agency				
Reference	Bhatnager et al., 1980; Campbell et al., 1980, 1981; Hyde et al., 1985; Moorman et al., 1985; Pepelko et al., 1980b, 1981; Pepelko, 1982b; Pepelko and Peirano, 1983; Plopper et al., 1983			Laurie et al., 1980; Laurie and Boyes, 1980, 1981	
Engine type	Nissan CN 6-33, 3.24 L, 6-cylinder			3.24 L, 6 cylinder	
Operating mode	Federal short cycle			Federal short cycle	
Fuel type	No. 2 diesel			No. 2 diesel	
Fuel sulfur	0.15%			0.15%	
Exposure regime	8 h/d, 7 d/week, 124 weeks			8 h/d, 7 d/week, 16 weeks	
Exposure conditions	Control	Exhaust - weeks 1-61	Exhaust - weeks 62-124	Control	Exhaust
Particle conc. (mg/m ³)	0.00	6.34 ± 0.81	11.70 ± 0.99	0.01	5.97 ± 0.17 ^b
Particle size		90% < 1 µm by mass; 50% ≤ 0.3 µm by mass			
CO ₂ (%)	0.04 ± 0.002	0.30 ± 0.04	0.52 ± 0.04	0.05 ± 0.00 ^b	0.28 ± 0.01 ^b
CO (ppm)	2.20 ± 0.50	20.17 ± 3.01	33.30 ± 2.94	1.86 ± 0.06 ^b	19.20 ± 0.35 ^b
NO ₂ (ppm)	0.03 ± 0.03	2.68 ± 0.80	4.37 ± 1.19	0.03 ± 0.00 ^b	2.51 ± 0.10 ^b
NO (ppm)	0.05 ± 0.04	11.64 ± 2.34	19.39 ± 3.80	0.08 ± 0.01 ^b	11.14 ± 0.43 ^b
SO ₂ (ppm)	0.03 ± 0.02	2.12 ± 0.58	5.03 ± 1.03	0.46 ± 0.02 ^b	1.82 ± 0.07 ^b
SO ₄ ⁻² (µg/m ³)	-	-	-		
Ozone (ppm)					
Aliphatic aldehydes (ppm)	0.00	0.177 ± 0.043	0.338 ± 0.057		
Formaldehyde (ppm)	0.00	0.106 ± 0.029	0.251 ± 0.059		
Acrolein (ppm)	0.00	0.025 ± 0.003	0.034 ± 0.009		
NH ₄ ⁺	-	-	-		
THC (ppm)	2.82 ± 0.50	7.93 ± 1.42	11.02 ± 1.04	3.22 ± 0.08 ^b	7.29 ± 0.11 ^b
PAHs					
Benzo(a)pyrene		15.9 µg/g extract			
Benzo(e)pyrene		28.6 µg/g extract			
Benzo(a)anthracene		53.8 µg/g extract			
Benzo(k)fluoranthene		77.8 µg/g extract (k+b)			
Fluoranthene		155.8 µg/g extract			
Pyrene		198 µg/g extract			
Phenanthrene		145.2 µg/g extract			
Chrysene		71.6 µg/g extract			
Perylene		3.5 µg/g extract			
Indeno(1,2,3-Cd) fluoranthene		10.9 µg/g extract			
Indeno(1,2,3-Cd) pyrene		14.8 µg/g extract			
Benzo(ghi)perylene		21.1 µg/g extract			

^a All ± are S.D., unless specified otherwise.

^b Standard error of mean values.

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES^a

Facility/Sponsor	U.S. Environmental Protection Agency			
Reference	Wiester et al., 1980			Pepelko et al., 1980a
Engine type	Nissan CN6-33, 3.24 L, 6 cylinder			3.24 L, 6 cylinder
Operating mode	California cycle, modified			California cycle, modified
Fuel type	No. 2 diesel			No. 2 diesel
Fuel sulfur	0.15%			
Exposure regime	20 h/d, 7 d/week, 4 weeks			20 h/d, 7 d/week, 4 weeks
Exposure conditions	Control	Exhaust	Exhaust - irradiated	Exhaust
Particle conc. (mg/m ³)	0.00	6.32 ± 1.31	6.83 ± 1.44	6.40 ± 0.36 ^b
Particle size	0.1-1.0 μm			
CO ₂ (%)	0.04	0.261 ± 0.01	0.25 ± 0.03	0.26 ± 0.008 ^b
CO (ppm)	2.0	17.4 ± 2.5	16.7 ± 4.0	14.61 ± 0.90 ^b
NO ₂ (ppm)	0.07	2.3 ± 0.4	2.9 ± 0.7	2.13 ± 0.09 ^b
NO (ppm)	0.11	5.9 ± 0.6	5.0 ± 1.2	6.13 ± 0.18 ^b
SO ₂ (ppm)	0.0	2.1 ± 0.8	1.9 ± 0.8	2.10 ± 0.21 ^b
SO ₄ ⁻² (μg/m ³)	0.00	0.57 ± 0.12	0.57 ± 0.13	0.577 ± 0.019 ^b
Ozone (ppm)	0.0	0.0	<0.01	
Aliphatic aldehydes (ppm)				
Formaldehyde (ppm)				
Acrolein (ppm)				
NH ₄ ⁺				
THC (ppm)	0.00	31.6 ± 2.3	26.1 ± 1.6	31.56 ± 1.25 ^b
PAHs				
Benzo(a)pyrene				
Nitropyrene				

^a All ± are S.D., unless specified otherwise.

^b Standard error of mean values.

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES^a

Facility/Sponsor	U.S. Environmental Protection Agency					
Reference	Pepelko, 1982a			Lee et al., 1978, 1980		
Engine type	Nissan, 6 cylinder, 3.24 L			3.24 L, 6 cylinder		
Operating mode	California cycle, modified			California cycle, modified		
Fuel type	No. 2 diesel			No. 2 diesel		
Fuel sulfur						
Exposure regime	20 h/d, 7 d/week, 4 weeks			20 h/d, 9 weeks		
Exposure conditions	Control	Exhaust	Exhaust - irradiated	Control	Exhaust	Exhaust - irradiated
Particle conc. (mg/m ³)		6.40 ± 0.36	6.75 ± 0.39		6.32	6.83
Particle size (μm) MMD ^b (GSD) ^c						
CO ₂ (%)		0.247 ± 0.003	0.244 ± 0.007	0.040	0.252	0.255
CO (ppm)		16.9 ± 1.1	16.1 ± 1.3	2.0	15.7	15.4
NO ₂ (ppm)		2.49 ± 0.18	2.76 ± 0.15	0.07	2.19	2.73
NO (ppm)		5.71 ± 0.21	4.53 ± 0.15	0.11	5.85	4.94
NO _x (ppm)						
SO ₂ (ppm)		2.10 ± 0.21	1.86 ± 0.21		2.13	1.91
SO ₄ ⁻² (μg/m ³)		577 ± 19	569 ± 19	0.0	0.57	0.57
O ₂ (%)						
Ozone (ppm)						<0.01
Aliphatic aldehydes						
Formaldehyde (ppm)						
Acrolein (ppm)						
NH ₄ ⁺						
Hydrocarbons (ppm)		31.6 ± 3.8	26.1 ± 3.4	2.0	15.6	15.0
PAHs Benzo(a)pyrene						
Nitropyrene						

^a All ± are standard errors of weekly means.

^b Mass median diameter.

^c Geometric standard deviation.

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES^a

Facility/Sponsor	National Institute for Occupational Safety and Health			
Reference	Castranova et al., 1985; Fedan et al., 1985; Hahon et al., 1985; Lewis et al., 1986, 1989; Mentnech et al., 1984; Vallyathan et al., 1986			
Engine type	Caterpillar 3304, 7 L, 4-cycle			
Operating mode	8-mode mining cycle, 60% idling			
Fuel type	No. 2 diesel			
Fuel sulfur	0.34%			
Exposure regime	7 h/d, 5 d/week, 104 weeks			
Exposure conditions	Control	Exhaust	Coal dust	Exhaust + coal dust
Particle conc. (mg/m ³)			4.98 ± 0.82	3.23 ± 0.60
Respirable particles ^b (mg/m ³)		1.95 ± 0.25	2.00 ± 0.41	2.02 ± 0.30
Particle size (μm) MMD ^c (GSD) ^d		0.23 (± 2.5) ^e 0.36 (± 2.0) ^f		
CO ₂ (%)	0.08 ± 0.02	0.20 ± 0.06	0.09 ± 0.05	0.20 ± 0.07
CO (ppm)	2.2 ± 0.9	11.5 ± 3.1	2.2 ± 0.9	10.9 ± 2.8
NO ₂ (ppm)	0.06 ± 0.04	1.5 ± 0.5	0.06 ± 0.05	1.6 ± 0.5
NO (ppm)	0.08 ± 0.14	8.7 ± 3.6	0.08 ± 0.29	8.3 ± 3.2
SO ₂ (ppm)		0.81 ± 0.38	0.01 ± 0.07	0.61 ± 0.29
SO ₄ ⁻² (μg/m ³)		29.0 ± 24.9	16.8 ± 17.9	42.3 ± 33.8
Aliphatic aldehydes (ppm)	0.02 ± 0.01	0.12 ± 0.06	0.02 ± 0.01	0.12 ± 0.05
Formaldehyde (ppm)	0.0076 ± 0.0035	0.0383 ± 0.0230	0.0074 ± 0.0041	0.0374 ± 0.0266
Acetaldehyde (ppm)	0.0015 ± 0.0035	0.0387 ± 0.0153	0.0009 ± 0.0025	0.0377 ± 0.014
Acrolein (ppm)	0.0030 ± 0.0033	0.0602 ± 0.0245	0.0062 ± 0.0047	0.0578 ± 0.0205
NH ₃ (ppm)	0.52 ± 0.28	0.64 ± 0.71	0.57 ± 0.52	0.48 ± 0.55
NH ₄ ⁺ (ppm)		0.027 ± 0.0307	0.0065 ± 0.0143	0.0165 ± 0.0233
THC (ppm)	4.1 ± 1.9	7.5 ± 2.2 (cold)		7.4 ± 2.0 (cold)
PAH (μg/m ³) Benzo(a)pyrene		13.5 ± 6.8		10.2 ± 6.5
Benzo(a)anthracene		19.6 ± 9.9	3.2 ± 2.2	11.2 ± 5.2
Benzo(k)fluoranthene		5.6 ± 2.3		3.6 ± 2.4
Fluoranthene		139.3 ± 98.1	26.5 ± 11.5	67.5 ± 52.4
Pyrene		123.4 ± 72.2	32.3 ± 15.1	60.0 ± 36.6

^a All ± are S.D., unless specified otherwise.

^b < 7 μm.

^c Mass median diameter.

^d Geometric standard deviation.

^e Electrical aerosol size analyzer.

^f Scanning electron microscope.

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES ^a								
Facility/Sponsor	National Institute for Occupational Safety and Health							
Reference	Green et al., 1983; Rabovsky et al., 1986				Rabovsky et al., 1984			
Engine type	Caterpillar, 7 L, 4 cylinder, 4-cycle				Caterpillar, 7 L, 4 cylinder, 4-cycle			
Operating mode	8-mode mining cycle, 60% idling				8-mode mining cycle, 60% idling			
Fuel type	No. 2 diesel				No. 2 diesel			
Fuel sulfur	< 0.5%							
Exposure regime	7 h/d, 5 d/week, 12 mo.				7 h/d, 5 d/week, 24 mo.			
Exposure conditions	Control	Exhaust	Coal dust	Exhaust + coal dust	Control	Exhaust	Coal dust	Exhaust + coal dust
Particle conc. (mg/m ³)		2	5	3				
Respirable particles ^b (mg/m ³)		2.01	1.97	2.08		1.9 ± 0.3	2.1 ± 0.4	2.0 ± 0.3
Particle size (μm) MMD ^c (GSD) ^d								
CO ₂ (%)	0.08	0.21	0.09	0.20	0.07 ± 0.02	0.16 ± 0.04	0.08 ± 0.04	0.17 ± 0.06
CO (ppm)	2.3	12.7	2.4	11.1	2.0 ± 0.9	10.5 ± 2.3	2.1 ± 0.8	10.3 ± 2.0
NO ₂ (ppm)	0.04	1.6	0.04	1.3	0.06 ± 0.04	1.5 ± 0.5	0.07 ± 0.05	1.5 ± 0.05
NO (ppm)	0.07	9.7	0.08	1.3	0.08 ± 0.13	7.8 ± 3.1	0.08 ± 0.28	7.6 ± 2.8
SO ₂ (ppm)	0.01	0.83		0.56		0.6 ± 0.4	0.003 ± 0.05	0.5 ± 0.3
SO ₄ ⁻² (μg/m ³)								
Aliphatic aldehydes								
Formaldehyde (ppm)								
Acetaldehyde (ppm)								
Acrolein (ppm)								
NH ₃ (ppm)	0.63	1.13	0.83	0.54	0.5 ± 0.6	0.6 ± 0.8	0.6 ± 0.7	0.4 ± 0.3
NH ₄ ⁺ (ppm)								
THC (ppm)								
PAH (μg/m ³) Benzo(a)pyrene								
Nitropyrene								

^a All ± are S.D. unless specified otherwise.

^b < 7 μm.

^c Mass median diameter

^d Geometric standard deviation.

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES^a

Facility/Sponsor	General Motors Research Lab					
Reference	Barnhart et al., 1981, 1982; Chaudhari et al., 1980, 1981; Chaudhari and Dutta, 1982; Chen and Vostal, 1981; Dziedzic, 1981; Eskelson et al., 1981; Penney et al., 1981; Misiorowski et al., 1980, 1981; Navarro et al., 1981; Schneider and Felt, 1981; Schreck et al., 1980, 1981; Strom, 1984; Vostal et al., 1981; Wallace et al., 1987; White and Garg, 1981				Gross, 1981	
Engine type	1978 350D Oldsmobile, 5.7 L, 4-cycle				5.7 L	
Operating mode	1350 rpm, 96 N·m				1350 rpm, 96 N·m	
Fuel type	Amoco type 2D				Amoco type 2D	
Fuel sulfur	0.27%				0.27%	
Exposure regime	20 h/d, 5½ d/week, 104 weeks				20 h/d, 5½ d/week, 87 weeks	
Exposure conditions	Control	Exhaust	Exhaust	Exhaust	Control	Exhaust
Particle conc. (mg/m ³)	0.007 ± 0.009	0.258 ± 0.087	0.796 ± 0.228	1.533 ± 0.346	0.007 ± 0.009	1.533 ± 0.346
Particle size (µm) MMD ^b (GSD)		0.19			0.2	
CO ₂ (%)						
CO (mg/m ³)	2.2 ± 0.6	3.4 ± 0.8	5.3 ± 0.9	7.9 ± 2.1	1.9	7
NO ₂ (ppm)					0.5	
NO (ppm)					6.7	
NO _x (mg/m ³)	0.05	2.1 ± 0.6	5.0 ± 1.2	9.2 ± 1.6	<0.04	7.2
Sulfur (mg/m ³)					1.4	
SO ₂ (ppm)						
Aliphatic aldehydes						
Formaldehyde (ppm)						
Acrolein (ppm)						
NH ₄ ⁺						
THC (ppm)						
PAHs Benzo(a)pyrene						
Nitropyrene						

^a All ± are S.D., unless specified otherwise.

^b Mass median diameter.

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES^a

Facility/Sponsor	Inhalation Toxicology Research Institute			
Reference	Bice et al., 1985; Cheng et al., 1984; Henderson et al., 1983, 1985, 1988; Mauderly et al., 1983, 1984, 1987a, b, 1988; McClellan et al., 1986; Wolf et al., 1987			
Engine type	1980 Oldsmobile V8, 5.7 L			
Operating mode	Federal Test Procedure, urban driving cycle			
Fuel type	Phillips No. 2 diesel			
Fuel sulfur	0.34%			
Exposure regime	7 h/d, 5 d/week, 130 weeks			
Exposure conditions	Control	Exhaust	Exhaust	Exhaust
Particle conc. (mg/m ³)	0.013 ± 0.006	0.353 ± 0.071	3.469 ± 0.447	7.082 ± 0.808
Particle size (μm) MMD ^b (GSD) ^c		0.183 ± 0.04 (4.8 ± 0.28) ^d 0.262 ± 0.06 (4.2 ± 0.24) ^e	0.184 ± 0.02 (5.3 ± 0.64) ^d 0.249 ± 0.03 (4.5 ± 0.54) ^e	0.213 ± 0.06 (4.7 ± 0.94) ^d 0.234 ± 0.06 (4.4 ± 0.88) ^e
CO ₂ (%)	0.2005 ± 0.0390	0.2284 ± 0.0371	0.4355 ± 0.0590	0.6643 ± 0.1320
CO (ppm)	1.0 ± 0.7	2.9 ± 1.0	16.5 ± 7.1	29.7 ± 12.9
NO ₂ (ppm)	0	0.05 ± 0.09	0.34 ± 0.22	0.68 ± 0.48
NO (ppm)	0	0.7 ± 0.3	5.7 ± 1.5	10.0 ± 2.6
SO ₂ (ppm)				
SO ₄ ⁻² (μg/m ³)				
Aliphatic aldehydes (ppm)				
Formaldehyde (ppm)				
Acrolein (ppm)				
Ammonia (ppm)	1.1 ± 3.0	1.4 ± 1.3	0.9 ± 0.9	0.7 ± 0.6
Hydrocarbons (ppm)	2.6 ± 0.6	3.8 ± 0.9	8.7 ± 5.2	13.4 ± 8.3
PAHs Benzo(a)pyrene				
Nitropyrene				

^a All ± are S.D. unless specified otherwise; data for particles through 30 mo.; data for gases from 35th week through 30 mo.

^b Mass median diameter.

^c Geometric standard deviation.

^d Lovelace multiple jet impactor, mass median aerodynamic diameter.

^e Impactor/parallel flow diffusion battery, mass median diameter.

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES^a

Facility/Sponsor	Inhalation Toxicology Research Institute							
Reference	Inhalation Toxicology Research Institute - Annual Report, 1980				Mauderly et al., 1981 ^b			
Engine type	1980 GM, 5.7 L				1980 GM, 5.7 L			
Operating mode	California 7-mode urban cycle				California 7-mode urban cycle			
Fuel type	Phillips No. 2 diesel				Phillips No. 2 diesel			
Fuel sulfur								
Exposure regime	7 h/d, 5 d/week, 12 weeks				7 h/d, 5 d/week, 19 weeks			
Exposure conditions	Control	Exhaust	Exhaust	Exhaust	Control	Exhaust	Exhaust	Exhaust
Particle conc. (mg/m ³)	0.039 ± 0.020	0.230 ± 0.073	1.030 ± 0.340	4.260 ± 1.110	0.050 ± 0.024	0.210 ± 0.070	1.020 ± 0.350	4.380 ± 1.160
Particle size (μm) MMD ^c (GSD) ^d								
CO ₂ (%)				0.2080 ± 0.04				
CO (ppm)	1.1 ± 0.6	1.5 ± 0.6	3.7 ± 1.1	11.5 ± 2.6				
NO ₂ (ppm)				0.4 ± 0.4				
NO (ppm)				0.80 ± 0.25				
NO _x (ppm)								
SO ₂ (ppm)								
SO ₄ ⁻² (μg/m ³)								
O ₃ (%)								
Ozone (ppb)				14.6 ± 3.1				
Aliphatic aldehydes								
Formaldehyde (ppm)								
Acrolein (ppm)								
Ammonia	2.8 ± 0.7	3.2 ± 0.8	2.9 ± 0.9	2.5 ± 0.7				
Hydrocarbons (ppm)				4.0 ± 0.8				
HTHC (ppm)								
PAHs Benzo(a)pyrene								
Nitropyrene								

^a All ± are S.D. unless specified otherwise.

^b Concentrations of gaseous components reported to be proportional to these in 12-week study.

^c Mass median diameter.

^d Geometric standard deviation.

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES ^a										
Facility/Sponsor	Japan Automobile Research Institute Inc. (Health Effects Research Program - HERP)									
Reference	HERP 1988; Ishinishi et al., 1986; Ishinishi et al., 1989									
Engine type	Light duty, 1.8 L, 4-cylinder, swirl chamber					Heavy duty, 11 L, 6-cylinder, direct injection				
Operating mode	1700 rpm, eddy current dynamometer					1200 rpm, eddy current dynamometer				
Fuel type	Nippon Oil Co JIS No. 1 or 2 diesel					Nippon Oil Co JIS No. 1 or 2 diesel				
Fuel sulfur	0.41%					0.41%				
Exposure regime	16 h/d, 6 d/week, 30 mo.					16 h/d, 6 d/week, 30 mo.				
Exposure conditions	Control	Exhaust	Exhaust	Exhaust	Exhaust	Control	Exhaust	Exhaust	Exhaust	
Particle conc. (mg/m ³)	0.003	0.11	0.41	1.08	2.32	0.002	0.46	0.96	1.84	3.72
Particle size (μm) MMD ^b (GSD) ^c				0.19 (2.37-2.71)	0.21-0.22 (2.23-2.93)				0.20-0.23 (2.73-3.07)	0.25-0.28 (2.75-3.18)
CO ₂ (%)	0.026	0.050	0.105	0.219	0.418	0.035	0.084	0.140	0.215	0.360
CO (ppm)	0.80	1.23	2.12	3.96	7.10	0.63	2.65	4.85	7.75	12.91
NO _x (ppm)	0.011	0.08	0.26	0.70	1.41	0.021	0.46	1.02	1.68	3.00
NO (ppm)	0.033	1.16	3.81	9.44	18.93	0.042	5.71	12.11	19.99	34.45
NO _x (ppm)	0.044	1.24	4.06	10.14	20.34	0.061	6.17	13.13	21.67	37.45
SO ₂ (ppm)	0.06	0.38	1.06	2.42	4.70	0.06	0.98	1.79	2.82	4.57
SO ₄ ⁻² (μg/m ³)	0.41	18.8	62.4	151	315	0.49	62.9	111	198	361
O ₃ (%)	20.8	20.8	20.7	20.5	20.3	20.8	20.8	20.7	20.6	20.4
Aliphatic aldehydes										
Formaldehyde (ppm)	0.002	0.01	0.03	0.07	0.13	0.003	0.05	0.11	0.18	0.29
Acrolein (ppm)										
NH ₄ ⁺										
LTHC (ppm)	2.17	2.27	2.51	2.87	3.57	3.50	4.27	5.16	5.90	7.62
HTHC (ppm)	2.20	2.44	2.93	3.82	5.49	2.43	4.63	7.15	9.94	15.65
PAHs (ng/m ³) Benz(a)pyrene					5.3 ± 10.6					7.5 ± 3.2
Benz(k)fluoranthene					5.4 ± 7.7					6.0 ± 3.0
Benz(ghi)perylene					2.7 ± 3.9					8.9 ± 2.5
1-Nitropyrene					46.6 ± 44.0					43.4 ± 9.8

^a All ± are S.D., unless specified otherwise.

^b Mass median diameter.

^c Geometric standard deviation.

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES^a

Facility/Sponsor	Japan Automobile Research Institute Inc. (Health Effects Research Program - HERP)				
Reference	HERP, 1988; Ishinishi et al., 1986; Ishinishi et al., 1989				
Engine type	Heavy duty, 11 L, 6-cylinder, direct injection				
Operating mode	1200 rpm, eddy current dynamometer				
Fuel type	Nippon Oil Co JIS No. 1 or 2				
Fuel sulfur	0.41%				
Exposure regime	16 h/d, 6 d/week, 30 mo.				
Exposure conditions	Control	Exhaust, filtered	Exhaust	Exhaust, filtered	Exhaust
Particle conc. (mg/m ³)	0.004	0.005	0.39	0.019	2.99
Particle size (μm) MMD ^b (GSD) ^c					0.31-0.35 (2.58-2.83)
CO ₂ (%)	0.068	0.083	0.084	0.391	0.412
CO (ppm)	0.06	2.54	2.50	13.00	12.90
NO ₂ (ppm)	0.024	0.42	0.44	3.96	4.95
NO (ppm)	0.040	5.16	5.37	32.81	31.50
NO _x (ppm)	0.062	5.58	5.81	36.76	36.45
SO ₂ (ppm)	0.03	0.96	0.98	4.50	4.03
SO ₄ ⁻² (μg/m ³)	0.35	1.43	57.7	1.61	358
O ₂ (%)	20.8	20.7	20.7	20.4	20.3
Aliphatic aldehydes					
Formaldehyde (ppm)	0.003	0.04	0.04	0.24	0.20
Acrolein (ppm)					
NH ₄ ⁺					
LTHC (ppm)	3.62	4.43	4.41	7.79	7.68
HTHC (ppm)	2.38	3.74	4.53	12.68	13.79
PAHs Benzo(a)pyrene					
Nitropyrene					

^a All ± are S.D. unless specified otherwise.

^b Mass median diameter.

^c Geometric standard deviation.

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES^a

Facility/Sponsor	Fraunhofer Institut fur Toxikologie und Aerosolforschung				
Reference	Heinrich et al. 1982		Heinrich et al., 1986; Stober, 1986		
Engine type	2.4 L		1.6 L		
Operating mode	Constant load of 16kW, 2400 rpm		FTP (1972)		
Fuel type	European reference fuel		European reference fuel		
Fuel sulfur	0.36%		0.36%		
Exposure regime	7-8 h/d, 5 d/week, 104 weeks		19 h/d, 6 d/week, 120-140 weeks		
Exposure conditions	Exhaust	Exhaust, filtered	Control	Exhaust	Exhaust, filtered
Particle conc. (mg/m ³)	3.9 ± 0.5			4.24 ± 1.42	
Particle size (μm) MMD ^b	0.1			0.35 ± 0.10	
CO ₂ (%)	0.54 ± 0.15	0.52 ± 0.13	0.10 ± 0.01	0.38 ± 0.05	0.35 ± 0.05
CO (ppm)	18.5 ± 4.9	18.0 ± 4.4	0.16 ± 0.27	12.5 ± 2.18	11.1 ± 1.92
NO ₂ (ppm)	1.2 ± 1.7	1.0 ± 1.5	-	1.5 ± 0.33	1.2 ± 0.26
NO (ppm)	16.5 ± 5.8	17.2 ± 5.9	-	10.0 ± 2.09	8.7 ± 1.84
NO _x (ppm)	18.6 ± 5.8	19.2 ± 6.1	-	11.4 ± 2.09	9.9 ± 1.80
SO ₂ (ppm)	3.1 ± 1.8	2.8 ± 1.7	-	1.12 ± 0.89	1.02 ± 0.62
SO ₄ ⁻² (μg/m ³)					
O ₂ (vol%)	19.5 ± 0.6	20.0 ± 0.7			
Aliphatic aldehydes					
Formaldehyde (ppm)					
Acrolein (ppm)					
NH ₄ ⁺					
THC (ppm)	9.3 ± 4.6	7.9 ± 3.3	3.5 ± 0.29	5.5 ± 0.69	5.2 ± 0.65
CH ₄ (ppm)	3.0 ± 2.2	2.6 ± 1.8	2.3 ± 0.17	2.6 ± 0.19	2.4 ± 0.20
PAHs (μg/g part.):					
Benzo(a)pyrene	7.0			3 (13 ng/m ³)	
Benzo(e)pyrene	14.1			- (21 ng/m ³)	
Benz(a)anthracene	9.8				
Fluoranthene	134.6				
Pyrene	65.8				
Benzo(a)fluoranthene	5.4				
Benzo(b)fluoranthene	5.3			- (51 ng/m ³)	
Benzo(ghi)perylene	21.4				
Chrysene	25.7				

^a All ± are S.D. unless specified otherwise.

^b Mass median diameter.

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES ^a							
Facility/Sponsor	Fraunhofer Institut fur Toxikologie und Aerosolforschung						
Reference	Heinrich et al., 1979; Meiss et al., 1981						
Engine type	2.4 L						
Operating mode	Constant load of 16 kW, 2400 rpm						
Fuel type	European reference fuel						
Fuel sulfur	0.36%						
Exposure regime	7-8 h/d, 5 d/week, 5 mo.						
Exposure conditions	Control	Exhaust	Exhaust, filtered	Exhaust	Exhaust, filtered	Exhaust	Exhaust, filtered
Particle conc. (mg/m ³)		4		11		17	
Particle size (μm) ^b		0.1		0.1		0.1	
CO ₂ (%)	0.1	0.5	0.5	0.9	0.95	1.4	1.6
CO (ppm)	<1	11	11	25	27	42	45
NO ₂ (ppm)		0.6	0.5	1.5	1.3	2.6	2.7
NO (ppm)		25	22	43	43	75	68
NO _x (ppm)		26	23	45	44	78	71
SO ₂ (ppm)	<1	3	4	8	8	13	12
SO ₄ ⁻² (μg/m ³)							
O ₂ (vol%)							
Aliphatic aldehydes							
Formaldehyde (ppm)							
Acrolein (ppm)							
NH ₄ ⁺							
THC (ppm)	6	8	8	11	12	13	13
CH ₄ (ppm)		5	5	5	5	5	5
PAHs Benzo(a)pyrene							
Nitropyrene							

^a Values estimated from graphically depicted data.

^b Aerodynamic diameter of the modal peak of the particle mass distribution.

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES^a

Facility/Sponsor	Southwest Research Institute			
Reference	Kaplan et al., 1983; White et al., 1983			Kaplan et al., 1982
Engine type	5.7 L			5.7 L
Operating mode	Steady state, 1347 rpm, equivalent to constant 40 mph			Steady state, 40 mph
Fuel type	Emissions 2D			
Fuel sulfur	0.23-0.24%			
Exposure regime	20 h/d, 7 d/week, 65 weeks			20 h/d, 7 d/week, 12-13 weeks
Exposure conditions	Control	Exhaust	Exhaust	Exhaust
Particle conc. (mg/m ³)	0.01 ± 0.009	0.242 ± 0.049	0.735 ± 0.084	1.500 ± 0.136
Particle size (μm)		88-93% < 1.0 79-85% < 0.5	88-94% <1.0 76-84% <0.5	91-94% <1.0 81-85% <0.5
CO ₂ (%)	0.0649 ± 0.0020	0.0781 ± 0.0028	0.1026 ± 0.0043	0.1355 ± 0.0062
CO (ppm)	5.81 ± 0.2	6.39 ± 0.3	7.43 ± 0.3	9.40 ± 0.5
NO ₂ (ppm)				
NO (ppm)	0	0.56	1.69	3.42
NO _x (ppm)	0.05 ± 0.0	0.65 ± 0.1	1.85 ± 0.2	3.73 ± 0.4
SO ₂ (ppm)				
SO ₄ ⁻² (μg/m ³)				
O ₂ (%)				
Aliphatic aldehydes				
Formaldehyde (ppm)				
Acrolein (ppm)				
NH ₄ ⁺				
Hydrocarbons (ppm)	3.43 ± 0.2	3.76 ± 0.3	4.31 ± 0.3	4.99 ± 0.3
PAHs Benzo(a)pyrene				
Nitropyrene				

^a All ± are S.D. unless specified otherwise.

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES^a

Facility/Sponsor	Battelle-Geneva Research Center					Japan Anti-Tuberculosis Association		
Reference	Brightwell et al., 1986; Bernstein et al., 1984					Iwai et al., 1986		
Engine type	1.5 L					2.37 L		
Operating mode	FTP - 1972					Steady state, 1000 rpm		
Fuel type								
Fuel sulfur								
Exposure regime	16 h/d, 5 d/week, 104 weeks					8 h/d, 7 d/week, 96 weeks		
Exposure conditions	Control	Exhaust	Exhaust	Exhaust	Exhaust, filtered	Control	Exhaust, filtered	Exhaust
Particle conc. (mg/m ³)		0.7	2.2	6.6				4.9 ± 1.6
Particle size (μm) MMD ^b (GSD) ^c								
CO ₂ (%)				0.46 ± 0.03 ^e	0.47 ± 0.03 ^e			
CO (ppm)	1 ± 3			32 ± 11	32 ± 11		7.0 ± 1.4 ^d	7.0 ± 1.4 ^d
NO _x (ppm)							1.8 ± 1.8 ^d	1.8 ± 1.8 ^d
NO (ppm)				5.8 ± 2.0 ^e	6.0 ± 2.0 ^e			
NO _x (ppm)	0.1 ± 0.1			8 ± 1	8 ± 2		30.9 ± 10.9 ^d	30.9 ± 10.9 ^d
SO ₂ (ppm)							13.1 ± 3.6 ^d	13.1 ± 3.6 ^d
SO ₄ ⁻² (μg/m ³)								
O ₂ (%)								
Aliphatic aldehydes								
Formaldehyde (ppm)								
Acrolein (ppm)								
NH ₄ ⁺								
Hydrocarbons (ppm)				18.9 ± 4.1 ^e	18.8 ± 4.1 ^e			
PAHs Benzo(a)pyrene								
Nitropyrene								

^a All ± are S.D. unless specified otherwise.

^b Mass median diameter.

^c Geometric standard deviation.

^d Samples from dilution tunnel, exposure chamber reported to have approximately the same concentrations.

^e Data from first year of study (Bernstein et al., 1984).

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES^a

Facility/Sponsor	Battelle, Pacific Northwest Laboratory		
Reference	Karagianes et al., 1981		
Engine type	43 bhp, 3 cylinder		
Operating mode	Simulated mining cycle		
Fuel type	Equivalent to VV-F-800 A grade DF-2		
Fuel sulfur	-		
Exposure regime	6 h/d, 5 d/week, 87 weeks		
Exposure conditions	Control	Exhaust	Exhaust + coal dust
Particle conc. (mg/m ³)	-	8.3 ± 2.0	13.5 ± 4.0
Resp. particles (mg/m ³)		95% respirable	
Particle size (μm) MMD ^b (GSD) ^c		0.71 (2.3)	
CO ₂ (%)			
CO (ppm)		50 ± 3	
NO ₂ (ppm)		4-6	
NO (ppm)			
NO _x (ppm)			
SO ₂ (ppm)		<1	
SO ₄ ⁻² (µg/m ³)			
O ₂ (%)			
Aliphatic aldehydes (ppm)		<1	
Formaldehyde (ppm)			
Acrolein (ppm)			
Ammonia (ppm)		26-40	
Hydrocarbons (ppm)			
PAHs Benzo(a)pyrene			
Nitropyrene			

^a All ± are S.D. unless specified otherwise.

^b Mass median diameter.

^c Geometric standard deviation.

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES^a

Facility/Sponsor	University of Pittsburgh			National Board of Occupational Safety and Health - Sweden	Ministry of Supply Chemical Defense Experimental Establishment			
Reference	Battigelli, 1965			Ulfvarson et al., 1987	Pattle et al., 1957			
Engine type	7 hp, four cycle, single cylinder			1980 Volvo, 6 cylinder	0.568 L, single cylinder			
Operating mode				2,500 rpm	1,600 rpm; A - no load; B - load; C - load plus worn injector; D - no load, high fuel-air ratio.			
Fuel type					47 cetane			
Fuel sulfur					0.51%			
Exposure regime	15-60 min			3 h, 40 min	5 h			
Exposure conditions	Dilution A	Dilution B	Dilution C	Exhaust	A	B	C	D
Particle conc. (mg/m ³)				0.6	74	122	53	1,070
Particle size (μm)								
CO ₂ (%)	0.1	0.9	1.1					
CO (ppm)	<20	30	55	4.63	560	410	380	1,700
NO ₂ (ppm)	1.3	2.8	4.2	2.07	23	51	43	12
NO (ppm)				4.56				
NO _x (ppm)					46	209	174	44
SO ₂ (ppm)	0.2	0.5	1					
SO ₄ ⁻² (μg/m ³)								
O ₂ (%)	20.5	20.0	19.5					
Aliphatic aldehydes	<1.0	<1-2	1-2		16 ^b	6.0 ^b	6.4 ^b	154 ^b
Formaldehyde (ppm)	<0.1	<0.1	<0.1	0.04				
Acetaldehyde				0.17				
Acrolein (ppm)	<0.05	<0.05	<0.05					
NH ₄ ⁺								
Hydrocarbons (ppm)	<2.0	2.5	3.2					
Benzene (ppm)				0.06				
Toluene (ppm)				0.35				
PAHs (μg/m ³): Benzo(a)pyrene				640				
Nitropyrene								

^a All ± are S.D. unless specified otherwise.

^b As formaldehyde.

APPENDIX A. EXPERIMENTAL PROTOCOL AND COMPOSITION OF EXPOSURE ATMOSPHERES ^a							
Facility/Sponsor	U.S. Environmental Protection Agency						
Reference	Gillespie, 1980; Hyde et al., 1980; Malanchuk, 1980; Orthoefer, 1980; Stara et al., 1980						
Engine type	Automobile gasoline engine						
Operating mode	Urban cycle						
Fuel type							
Fuel sulfur							
Exposure regime	16 h/d, 7 d/week, 68 mo.						
Exposure conditions	Control	Non-irradiated gasoline exhaust (R)	Irradiated gasoline exhaust (I)	SO ₂ + H ₂ SO ₄	R + SO ₂ + H ₂ SO ₄	I + SO ₂ + H ₂ SO ₄	Nitrogen oxides
Particle conc. (mg/m ³)							
Particle size (μm)							
CO ₂ (%)							
CO (ppm)	4.9	97.5 ± 10.0	94.5 ± 19.6	-	98.4 ± 13.8	-	-
NO ₂ (ppm)	0.04	0.05 ± 0.02	0.94 ± 0.36	-	0.05 ± 0.03	0.89 ± 0.36	0.64 ± 0.12
NO (ppm)	0.04	1.45 ± 0.42	0.19 ± 0.29	-	1.51 ± 0.44	0.19 ± 0.29	0.25 ± 0.06
NO _x (ppm)							
SO ₂ (ppm)	0.03	-	-	0.42 ± 0.22	0.48 ± 0.23	0.42 ± 0.21	-
H ₂ SO ₄ (ppm)	-	-	-	0.02 ± 0.01	0.02 ± 0.01	0.03 ± 0.01	-
Oxidants (ppm as O ₃)	0.02	-	0.20 ± 0.09	-	-	0.20 ± 0.08	-
Aliphatic aldehydes							
Formaldehyde (ppm)							
Acrolein (ppm)							
NH ₄ ⁺							
Hydrocarbons (ppm as CH ₄)	2.7	27.5 ± 4.4	23.9 ± 6.1	-	27.4 ± 4.3	23.9 ± 6.0	-
PAHs Benzo(a)pyrene							
Nitropyrene							

^a All ± are S.D. unless specified otherwise.